ENGINEERING REPORT ON THE OAO-2 WISCONSIN EXPERIMENT PACKAGE

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ABSTRACT

The continued useful operation of the OAO-2 Wisconsin Experiment Package (WEP) for almost three years after its December 1968 launch is evidence of a superior engineering accomplishment. Reliability features of the experiment concept and design which have contributed to its long life are presented. Data anomalies and partial failures are summarized along with conclusions regarding their causes. The thermal, vacuum and radiation effects of the space environment are shown to be minimal and quite localized within the WEP.

I. INTRODUCTION

The purpose of this document is to provide an engineering report on the performance of the Wisconsin Experiment Package (WEP), one of two major experiment equipments which were launched into a circular orbit as a part of the Orbiting Astronomical Observatory (OAO-2) in December 1968. At the time of this writing the WEP is in its third year of operation with the OAO spacecraft. The scientific achievements of this program are unparalleled in the field of ultraviolet astronomy. The continued experiment operation and collection of valuable scientific data over such a long time period is evidence of a superior engineering accomplishment.

This document presents the scope of the WEP engineering accomplishments, the WEP data anomalies and partial failures which have occurred, the observed effects on the WEP of the space environment and other orbital and spacecraft parameters. A summary of observed photometry and filter variations and their causes is presented. It is anticipated that the infor-

mation presented will be useful to astronomers in analyzing their recovered data and also useful to engineers and designers of future space experiments. A functional description and general performance have been reported by Code et al. (1970).

II. ENGINEERING OBJECTIVES

The objective of the engineering effort was to design and fabricate the seven telescopes and associated electronics, optics, structures and mechanisms within the space, weight, environment and power constraints imposed, while still providing for a one year life in orbit. The 15 watt average power constraint alone dictated pulsed or stepping filter, aperture and grating drive mechanisms as well as unique (to the 1961-1965 design period) designs for analog amplifiers, digital electronics and high efficiency power supplies. The space vacuum and thermal constraints required extreme care in selection of materials and lubricants of exposed components and materials. The 500 pound weight limitation ruled out brute force techniques for maintaining structural integrity and the precise optical alinements necessary for telescope construction and mounting.

Despite all of these interesting and challenging design problems, it was readily evident that the most difficult task would be the accomplishment of the reliability goal of one year of operational life in orbit.

III. RELIABILITY FEATURES

The basic scientific concept provided for parallel and redundant means of collecting spectral intensity information on celestial objects. Certain optical filters of the four stellar photometers were used redundantly in adjacent instruments so that the loss of a single stellar photometer would not cause a spectral gap to exist in the data. Similarly, the nebular filters redundantly covered much of the stellar spectral range. Further, Scanning Spectrometer No. 1 covers the approximate wavelength band of 1000-2000 Å while Spectrometer No. 2 covers from 2000 to 4000 Å. Thus, the ultraviolet spectral range is again covered redundantly by these instruments.

Since the instruments contained measuring redundancy, it was possible and profitable from a reliability viewpoint to make their control and data collection electronics independent of one another to the maximum extent possible. Thus, command control data entry is in series form only at the spacecraft command line input isolation point. The WEP internal command storage is by means of parallel input registers rather than serial type shift registers. Also, separate exposure time generators exist for each stellar, and the nebular, as well as

one for the two spectrometers. Filter command decoding circuits and drive circuits are all separate for each stellar and the nebular. While it was not practical to provide a separate power supply for each instrument, two supplies of each of the ±10 volt, ±15 volt and high voltage supplies were provided. These are changeable on command from the ground. Further, it was made possible to collect analog data if the ±10 volt supplies failed or digital measurement data if the ±15 volt supplies failed. The ±10 and ±15 volt power supply line to each instrument in the PIP package was fused so that a short on one line for one photometer would not disable other photometers. High resistance (3.3 meg or 91.1 megohm) series isolation resistors were used in the high voltage line to each phototube, so that short circuits or heavy saturation of one tube would not seriously affect the output from other tubes.

All the standard reliability techniques of the time relative to "worst case" designs, component selection, screening, derating, high vacuum sample, testing etc. were utilized. Extremely detailed qualification tests on the prototype and acceptance tests on the flight models were made at both the manufacturer's site and at Goddard Space Flight Center. Any failures known to occur were diligently followed up to determine the cause and rectify the problem. Rescheduling of tests was closely followed and coordinated by GSFC project and test personnel in cooperation with the WEP group. Given this professional concept and design program, it was the dedication of people (scientists, engineers and administrators alike) to the idea of reliability which ultimately paid off in equipment performance.

IV. INTERNAL WEP ANOMALIES AND FAILURES

a) General

This section presents the WEP anomalies and failures which have occurred, and the analyzed cause and effect of the observed "happenings".

b) HVPS Loading

Saturation of certain of the instrument detector tubes loads the high voltage power supply (HVPS) to an extent that other instruments' sensitivity may be affected. The loading effect is illustrated by the higher than normal HVPS status indicating lower than normal HVPS output voltage. One can project from the WEP data an incident light level having a potential 100 μa Stellar 1 tube current (a 100-fold increase over 1 μa at E1 for full saturation). However, the use of the series 91.7 megohm resistor in both the Stellar 1 and 2 and

Spectrometer No. 1 high voltage power line provided self-limiting of the photomultiplier tube current at about 6 microamps. This self-limiting feature has saved the tubes from deterioration or destruction due to the extremely high incident light levels which occur when the WEP views the sunlit earth. The self-limiting also reduces the dark current recovery time following the high light level exposure.

c) HVPS Arcing

It has been concluded that WEP HVPS arcing took place between 2130 on January 16, 1969 and 1530 on January 17, 1969, about 1-1/2 months after launch. This time period also coincided with a spacecraft loss of control and recovery and recharge of spacecraft batteries. Manually reduced WEP data showed high voltage status variations beyond that attributable to HVPS loading. Uncommanded aperture changes, a collimation status change and filter wheel position changes all occurred during this period. It was also at this time that both the nebular filter wheel and the nebular aperture became permanently stuck, apparently from a blown fuse in the -10 volt power line to the nebular. Data immediately following this time period indicated that the HVPS had switched itself (without command) to the redundant high voltage power supply. The new (different manufacturer) HVPS has performed admirably since that time and no commands have been sent to try the original supply.

It is theorized that the WEP HVPS arcing caused radiative pickup in the aperture, collimation and filter wheel drive monostables of the WEP Prime Instrument Package (PIP), resulting in the erroneous (uncommanded) mechanism status indications. One of the strong radiative transients probably blew the 10 volt fuse to the nebular. The lack of significant changes of the WEP Control Electronics Package (CEP) controlled exposure time status compared to mechanism changes indicates a localization of the fault to the PIP rather than erroneous commands being issued by the spacecraft through the CEP. HVPS arcing could cause conductive pulsing of the WEP-PIP internal 28 volt dc power line which could cause status changes similar to those detected. However, one would expect to notice ±10 and ±15 volt dc internal supply changes with strong conductive pulsing and these changes did not occur. The RFI filters in the +28 volt line and return to the spacecraft provide good isolation of WEP conductive pulsing back into the spacecraft +28 volt dc line.

The cause of HVPS arcing is attributed to the PIP entrapment of some of the spacecraft gas being fired during loss of spacecraft control and subsequent orientation corrections. Current procedures call for WEP power to be turned off when

spacecraft control or power problems occur. Improved OAO spacecraft recovery techniques now require little or no gas ejection.

d) Second Half of Data Storage

Analog WEP data on occasion has been noted to be erroneous on words 1, 4, 7, 10 and 13. Some of the stellar digital data is also erroneous at the same time. The cause of these errors has been traced to bit errors occurring during readout of the WEP data from the second half of the spacecraft data storage. GSFC has been able to verify these bit errors. The +15 volt status (word 10) drops suddenly by 0.16 volts from its normal very steady value. The Control Electronics Temperature status (word 13) also drops by 0.16 volts. The normally .00 Stellar 4 analog data (word 4) will occasionally go to 0.16 volts. Stellar 1 and Spectrometer No. 2 analog measurements vary radically. Command programming and data reduction techniques avoid the use of the second half of spacecraft data storage whenever possible.

e) Stellar 1 Digital Count

Digital counting of Stellar 1 data occasionally is erroneous. During the time periods of this anomaly, data counts show up as one, or one plus only one other binary stage. Thus, while the count one predominates, counts of 1, 17, 33, 65 and 129 often appear to the exclusion of other non-binary plus one count data. This anomaly is easily detectable on manual comparison of stripped data to analog data, but the anomaly may not be so obvious when computer averaged data are presented.

The cause of this anomaly is attributed to the first stage of the Stellar 1 data output counter in the Control Electronics Package being stuck in a binary ONE condition. This prohibits the normal flow of counts from triggering the next stage (2 level) because of the lack of a full one to zero transition. It has been noted in ground testing that attempts to cause the correct transition by incoming data pulses may result in occasional small pulses being amplified by the 2, 4, 8, and succeeding level stages until a sufficient pulse transition causes one downstream binary stage to flip. Thus, <u>all</u> data outputs have the one level count, and occasionally one binary stage well away from one is activated.

The anomaly is quite rare, but exists at least from the beginning of week 31-1 starting on January 21, 1970 and then clears itself up on January 25, 1970. This slow rate of change is indicative of a thermal or thermal transient basic cause for the sticking flip-flop. Weekly CEP thermal status plots did show a greater than normal 10°C thermal variation during

mid-January but these changes steadied out on January 22, 1970.

f) Stellar Filter Wheel Anomalies

(i) General

The stellar filter wheel control circuit operates as a closed loop servo. A filter wheel command is entered in a digital register and the filter wheel steps at a 1 pulse per second rate until a feedback commutator detects that the digital status agrees with the registered command. Redundant codes are used such that all possible bit combinations of each four bit filter wheel command will result in one of the five filter position commands. Thus, a single "noisy" or random command cannot cause the filters to continuously step. Also, any one of the four bit command register stages can fail, and all filter positions can still be commanded.

(ii) Commutator Failure and Wear

Stellar 2 has been noted to have an occasional poor commutator status pickup in the filter 4 calibration slide status position. Typical data for filter 4 E2 or 1 second exposure results in the six mode A data sets being separated by two seconds. The Stellar 2 filter position status for the six measurements were 0, 1, 3, 5, 2 and 0. This is exactly the status which would result if the wiper of the commutator were not making proper contact with the fixed printed circuit board commutator coder on position No. 4. The recurrence of this anomaly was noted only four times in the 20 to 30 Stellar 2 F4 commands during the week 42-3 and was not noted on other positions or stellars during four sample weeks of 1970 data. During late 1970 and early 1971 the Stellar 2 filter wheel had become stuck and then unstuck. It is currently being left at the useful F5 position. The progression of both the Stellar 2 filter wheel conditions is indicative of mechanical wear nearing the end of filter stepping life.

(iii) Filter Cycling

During 1969, filter cycling commands were occasionally sent which should cause the six filter status readings for all stellars to be 1, 2, 3, 4, 5, 1 successively. This command promotes a noisy mechanical and electrical response which increases the probability of the Stellar 2 described anomaly occurring in other stellars. This command also reduces the data accuracy by eliminating the potential for six point averages at each reading. The filter cycling command is limited to single exposure settings which could result in a saturated

reading for the calibration slide or one of the other filters. The recovery time from saturated readings may affect the first sample of the following filter reading. For all of these reasons, the filter cycling command is no longer being used.

(iv) Charge Capacitor Fusing

The power for the filter stepping drive mechanism is derived from the regulated 28 volts provided by the spacecraft. In order to isolate high current stepping transients from the spacecraft power lines, separate energy storage capacitors are used for each photometer along with charge current limiters between the power source and the capacitor. Fusing of the current limited line was done to preclude capacitor or drive circuit shorting failures from drawing continuous current from the spacecraft 28 volts. Test failures of fuses in system tests at GSFC resulted in resistor by-passing of the fuses to a degree such that a storage capacitor could still charge if a fuse were blown, but that the charge time would be longer. The increased charge time is of the order of 16 seconds for satisfactory charge with the fuse blown as versus much less than 1 second with a good fuse. It is not clear whether some of the fuses have blown at the time of this writing. However, commands are being typically issued for only one sequential step (of all four stellars if desired) at a time. This technique conserves the energy stored on a capacitor, and reduces the recharge time.

V. PHOTOMETER PARAMETER CONSISTENCY

Each of the seven WEP instruments uses a photomultiplier tube to convert its input optical signal to an output electrical signal. Each photon of tube input light intensity is converted to an electrical pulse by the photomultiplier tube and its attached pulse preamplifier. The pulses are fed to two parallel detection circuits. One is a digital detection and six stage binary precounter, followed by an eight stage binary digital output measurement counter. The other parallel chain integrates the detected pulses and presents an analog current to an analog amplifier which produces an analog output measurement voltage.

The digital measurement counter output count represents the sum of pulse counts due to light photons on the tube, plus the tube dark current count, plus tube external noise counts, plus an average digital offset of 0.5 count. The tube dark current count plus the tube external noise count are generally lumped together as a total "dark" count. Due to the six stage binary precounter each output signal plus dark count represents 64 photo-electron pulse counts detected by the photomultiplier

tube for any given filter and exposure time. A full scale digital output measurement count is 2^8 minus 1 or 255 units of digital output data which is available for each of the four programmable exposure times. The precounter receives continuous pulses from the detector tube, whereas the input to the output counter is reset and gated on by the start of an exposure time and off at the end of the exposure. If the precounter last stage is in a ONE condition when the output counter is gated on, a one count offset is introduced to the output. Since the precounter is in the ONE condition 50% of the time, a 0.5 count average offset is taken from all digital measurements regardless of exposure. Experience has shown that spacecraft day, viewing the sunlit earth, or passing through the South Atlantic Radiation Anomaly, often contributes sufficient dark count to mask out the actual star signal. Command programming is such that useful digital and analog data is taken only during spacecraft night and when not in a predetermined South Atlantic Anomaly location. There is no digital overflow indicator so it is well to avoid digital overflows by good programming. One technique of measurement when a question regarding overflows is likely, is to program at least two different adjacent exposures for the same object and same filters. Another technique is to predetermine an analog voltage per digital overflow ratio, then determine overflows from the analog voltage measured by the same instrument. Still a third technique is to relate another instrument reading to the measurement count in question. The ground data reduction programs incorporate the best methods of establishing overflows for each instrument.

The analog measurement circuitry is composed of a dc operational amplifier with relay controlled sensitivity ranges. The operational amplifier has a balanced electrometer tube pair input stage followed by a transistorized amplifier. The selectable sensitivity ranges are 10^{-6}, 10^{-7}, 10^{-8} and 10^{-9} amperes full scale. These commanded gain changes are automatically accomplished with the 1/8, 1, 8 and 64 second exposure time commands used for the pulse measurement circuitry. As these amplifiers are used for integrating, specific time constants are provided for each range. These are 1/4 of the associated exposure time: i.e., 1/32, 1/4, 2 and 16 seconds.

The measured analog output voltage consists of the sum of the analog signal due to incident light on the tube, an analog tube dark current signal combined with external noise effects, and an analog offset voltage. The spacecraft day and radiation effects which contribute to digital noise also contribute to analog noise. The gain of each analog amplifier is linear to about 0.5% over each sensitivity range. The linearity at zero input does not correspond to zero output volts, which gives rise to the fixed analog offset for all sensitivi-

ty ranges. Taking two measurements on the same object with the same filters but different exposures within about 5 minutes of time allows one to consider dark currents constant and thus to calculate analog offset. These calculated offsets are averaged over about one week of time and fixed values used as inputs to data reduction programs. The offsets may be positive or negative, and each amplifier offset may vary significantly over more than a one week period.

The digital measurement count has proven to be generally more consistent and valuable than the analog voltage output. The digital sensitivity is higher and consequently it registers significant output for less of a filtered light input to the tube. The resolution of both channels is limited to one part in 256 for a given gain setting. This is because of the 8 binary bit limitation on available digital data output counts and the 8 binary bit analog to digital converter used on the analog channels for data transmission. Thermal and long time variations in the photometer analog and digital outputs have been noted on repeated measurements of calibration slide outputs. The thermal induced variations are of the order of 15% maximum on analog outputs and about 3% maximum on digital outputs. The linear time related variations may run from a maximum of 40% on the analog outputs to 8% maximum on the digital outputs. The variations are highest on the most active tubes (i.e. Stellar 1 which generally observed high light levels) and lowest on the least active far ultraviolet sensitive tubes (Bendell 1971). These thermal and time variations are of little consequence to the stellar photometers since the calibration slide data is used to normalize the measurement data in the data reduction programs. The spectrometers have no built-in calibration source. Consequently, the thermal and aging effects on these units must be obtained from examination of repeated scans, widely separated in time, of reference stars. Preliminary results show significant effects may exist on Spectrometer No. 1. However, Figure 1 plots raw Spectrometer No. 2 digital data on a reference star along with the difference in raw counts over a complete scan separated by a time period of 1-1/2 years. The difference plot shows less than 1% or ±1 count difference in the raw data. Spectrometer No. 1 digital sensitivity was known to increase during late 1969 and early 1970, possibly due to a stuck bit in the precounter, such as that which was previously described as an anomaly for the measurement counter of Stellar 1. This sensitivity variation is slow enough in occurring that it has no effect on the examination of a scan for relative peaks and valleys, indicating emission or absorption spectral lines. It happens that the result of a stuck bit in the precounter is to yield a much higher resolution of peaks and valleys in the data in the measurement

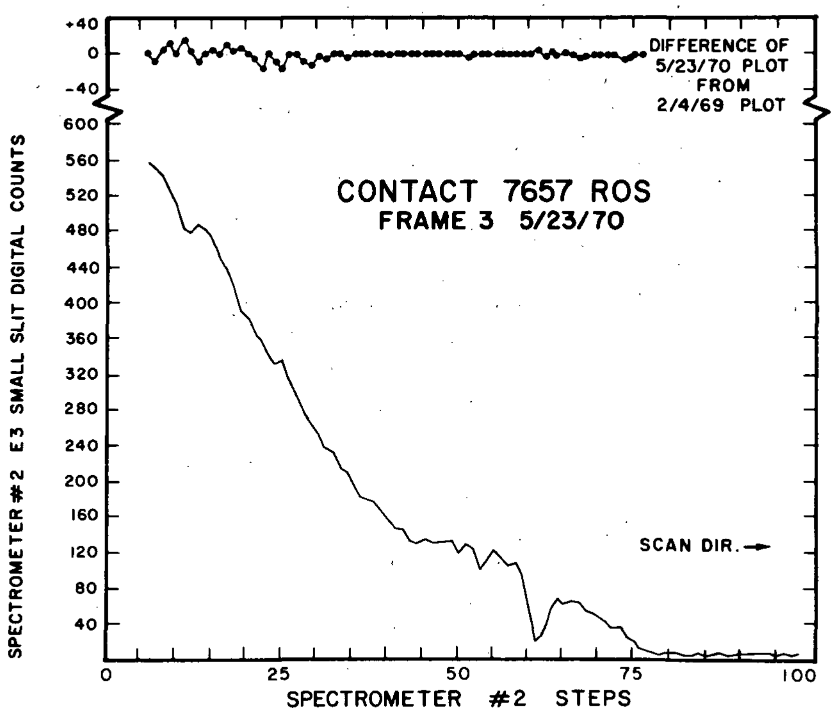

Figure 1.—Spectrometer No. 2 Eta UMa scan.

counter. Consequently, the fault has yielded some excellent data on relatively dim stars.

VI. FILTER CONSISTENCY

a) General

Given the relative consistency of the photometers coupled with the ability to compensate for thermal and time related variations in the photometers, the tools are available to analyze the consistency of the parameters in the optical path; namely the optical filters and mirrors. As will be subsequently shown, there are no major degradations of data taken on repetitive measurements of reference stars for most of the optical filters. One can thus conclude that the reflecting optics have suffered no degradations, and analyze the individual filter data in terms of the filter consistencies.

Table 1 summarizes the nature of the individual WEP filters and all elements within each Stellar affecting detected optical bandwidth. The table and all further comments regarding filters and filter degradation are derived from a letter by Dr. A. D. Code of the University of Wisconsin Space Astronomy

Table 1. WEP - Filter System Characteristics

Instrument	Filter	Type	$\bar{\lambda}$ Å	$\bar{\lambda}$BW	λ_{eff}
EMI 6256B CsSb(1700-6000)					
S1	F1	I.F.+UG11	3317	540 Å	3357±20
	F3	BG12+GG13	4252	840	4290±35
	F4	I.F.+F.Q.	2985	420	3075±25
EMI 6256B CsSb(1700-6000)					
S2	F1	I.F.+F.Q.	2035	480	2249±50
	F2	I.F.+F.Q.	2945	440	3062±25
	F5	I.F.+F.Q.	2386	330	2493±35
ASCOP 541F CsTe(1050-3500)					
S3	F1	I.F.+F.Q.	1913	260	2107±20
	F2	I.F.+F.Q.	2462	380	2589±30
	F5	I.F.+CaF_2	1679	260	2217±50
ASCOP 541G CsI(1050-1950)					
S4	F1	I.F.+CaF_2	1554	240	1662±15
	F3	I.F.+CaF_2	1430	240	1601±30
	F4	I.F.+LiF_2	1332	200	1556±50

Laboratory. Stellar 1 and Stellar 2 employ EMI 6256 Cs Sb photomultipliers with a sensitivity from about 1700 Å to 6000 Å. Stellar 3 employs an ASCOP-541F Cs Te photomultiplier with a cleaved LiF_2 window and a sensitivity from about 1050 Å to 3500 Å. Stellar 4 uses an ASCOP-541G CsI tube with a response from 1050 Å to about 1950 Å. The interference filters (I.F.) are first order filters deposited on a glass, fused quartz (F.Q.) suprasil, CaF_2 or LiF_2 substrate as indicated by Table 1. The wavelength $\bar{\lambda}$ is the constant energy wavelength for the preflight interference filter curves and λ_{eff} is the effective wavelength for a solar energy distribution neglecting the effects of the transmission due to pinholes. $\bar{\lambda}$BW is an indicator of the half power interference filter bandwidth around $\bar{\lambda}$.

The particularly useful filters for late type celestial objects are S1F1 (3317 Å), S3F2 (2462 Å), S3F1 (1913 Å) and S4F1 (1554 Å). Figure 2 illustrates the band passes for the S1F1 filter along with the bandwidth properties of the substrate and photomultiplier response. The S1F1 spectral characteristic is defined by the UG11 as well as the interference filter. It can be shown that the S4F1 is also defined by the ASCOP tube response and the CaF_2 substrate. Should the interference filter vanish, the bandpass would still be at about the same effective wavelength with an increase in width of about 100 Å. S3F2 and S3F1 are not as tightly defined but the suprasil substrate and ASCOP tube definitely eliminate the effects of Lyman alpha leaks on the low wavelength end and red leaks on the high end.

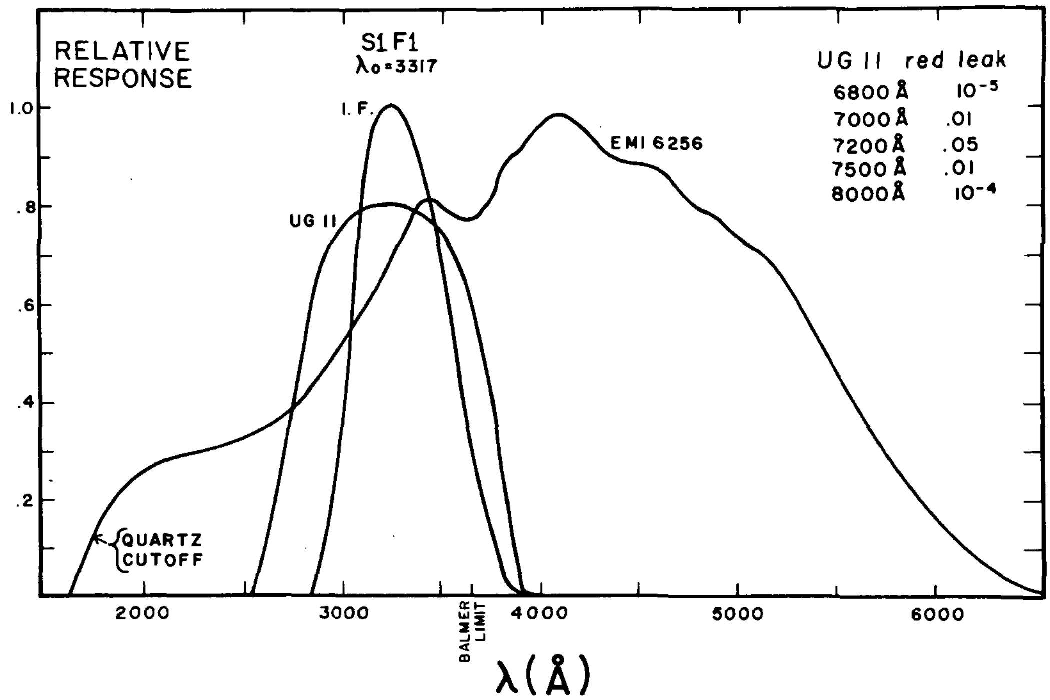

Figure 2.—Stellar 1 Filter (S1F1) optical element response versus wavelength.

b) Pinholes in the Interference Filter

The transmission longward of the maximum for a perfect filter would be determined by the transmission of the aluminum layers of the interference filter except as limited by tube and substrate bandwidth. The perfect filter longward transmission is of the order of 10^{-4} for the layer thickness employed. Pinholes which develop in the filter increase the transmission.

Laboratory tests have shown that longward filter transmissions after abrasion were 1.2×10^{-3} at 4037 Å and 9×10^{-4} at 5210 Å. It is assumed that these transmissions represent a worst case for any flight interference filter. Pinholes in Stellar 2 interference filters would have little effect towards the short wavelength end because of the EMI tube and fused quartz cutoff characteristics. However, pinholes on the S2F5 (2386 Å) filter having a longward wavelength "red leak" of the order of 10^{-3} could produce equal response from red leak as from the normal filter bandwidth for solar type stars. This is because these stars have a high concentration of red energy relative to the filter bandwidth energy. Just such a situation appears to have occurred for the S2F5 (2386 Å) filter. To a lesser degree the red leak has affected the S2F2 (2945 Å) filter and to a greater degree the S2F1 (2035 Å) filter. Red leaks have little effect on Stellar 1 because its interference filters are located at high energy red wavelengths. Red leaks have little effect on Stellar 3 and 4 because of bandwidth limitations of the ASCOP tubes.

The cause of pinholes has not been traced to the space environment since no time related degradation has as yet been found. The S2F1 (2035 Å) filter as was noted has been giving unreliable results on late type stars. Tests were made using a bright red giant star object while offsetting the WEP bore sight. These tests indicated that one half the filter transmits about 10 times the radiation that the other half does. This effect is not noticeable on early type stars and therefore suggests that it is the red leak that is variable across the filter surface. Perhaps a part of this filter has an abrasion or finger print that increased the transmission in the red tail.

c) Fluorescence and Calibration Slide Leaks

The only material that appears to fluoresce significantly is CaF_2. This affects S3F5 (1679 Å) but does not affect the CaF_2 substrate filters in Stellar 4 because the CsI photocathode is not sensitive to the wavelengths at which fluorescence occurs.

Two runs with the OAO spacecraft sun shade closed have allowed us to determine the effects of the Cerenkov source on filter biases. These dark count filter biases are summarized in Figure 3 for Stellar 3 and 4. When Stellar 3 F3 calibration is in front of the photomultiplier tube, we get approximately 16000 E4 counts primarily due to Cerenkov radiation with a small part due to Beta particles. When moved from F3 position to F4 the counts are due to Beta particles passing through shielding and hitting the photomultiplier window. Assume there are 6.8 E4 counts measured on dark above dark

noise. When moved further from window to F5 the Beta particles going to the photomultiplier window drop the count to 1.0 E4 counts; however, the CaF_2 substrate fluorescence with radiation detected by the photomultiplier produces an additional 33.8 counts. In position F1 the effect of the calibration position on the photomultiplier tube produces 0.5 counts. Finally when the calibration position is again adjacent to the window in F2 the counts rise to 5.3 E4 counts.

Stellar 4 is similarly interpreted with the same small asymmetry. When the calibration position is in F2, we get 8960 counts. Since this photomultiplier is not sensitive to radiation longward of about 1800 Å the Cerenkov radiation which comes from suprasil is very weak and the effect is mainly from Beta particles. It was necessary to use a much stronger radioactive source in this photometer for that reason. When the source is moved from the F2 position to F3 we get 10.8 counts from Beta particles on the photomultiplier window. When moved to F4 this drops to 2.0 counts. At the dark position F5 we assume 1 count is registered. Finally in position F1 the counts return to 10.4 E4 counts. Stellar 4 contains two interference filters with CaF_2 substrates; since the photomultiplier is not sensitive to radiation longward of 1800 Å the fluorescence is probably not measurable. There is also reason to believe according to notes made in testing that S3F5 has the interference coating out away from the photomultiplier. This may not be the case for the Stellar 4 filters. It was intended to insert all filters with the interference layers inward.

Figure 3.—E4 dark counts as function of calibration position.

d) Time Related Degradation

Only one filter shows a serious degradation with time; this is the Lyman alpha filter S4F4. A plot was made which shows filter data of several Orion stars taken over 10,000 orbits or 1.9 years. The relative magnitude of the S4F1 data is quite consistent over this period of time which bodes well for the consistency of all the optical elements used in this most ultraviolet sensitive photometer. The S4F4 filter output, however, has linearly decreased by a factor of 2.4 over this time period. This filter is the only filter with a

lithium fluoride substrate and has apparently developed color centers (F centers) from particle bombardment. Both Stellar 3 and 4 have cleaved LiF_2 windows and Stellar 3 has a polished LiF_2 Fabry lens, but apparently these LiF_2 components are protected by the filter wheel and structure from damage from particles. This degradation, being linear, is predictable and therefore usable for time related corrective constants on past and future observations with this filter. The continued reduction of filter sensitivity only limits its usefulness for dim objects.

VII. STATUS AND CONCLUSIONS

A general WEP status in mid-1971 (2-1/2 years after launch) is that reliable photometry can be obtained on faint late type objects with all 12 stellar filters except S2F1 (2035 Å), S2F5 (2386 Å) and S3F5 (1679 Å). Stellar 2 filter is becoming stuck more often than not, but may be left in a useful filter position. The nebular photometer is useful only for calibration slide data, and the Spectrometer No. 1 digital sensitivity has become unreliable. The Spectrometer No. 1 analog is fair, and the Spectrometer No. 2 analog and digital continue to provide extremely valuable original data and backup data for stellar readings. The digital sensitivity is proving to be a most valuable and accurate tool for faint type objects. The system response is constant enough that if careful dark and sky readings are taken, then photometry accurate to ±1 output count on E4 is possible at night well out of the South Atlantic Anomaly. Conservative estimates for total operations to mid-1971 based on reduced data are summarized below.

- 40,000 steps of each Stellar filter wheel drive motor;
- 30,000 gain changes involving an estimated 20,000 operations of each of the two gain relays in each Stellar photometer;
- 260,000 steps of each of the two scanning Spectrometer stepping motors;
- 1,000,000 data points from the four Stellars in Mode A;
- 500,000 data points from the two Spectrometers in Mode C.

This status and these quantities of mechanical operations and data observations achieved far outstrip the accepted standards used for evaluation of reliability prior to launch.

The conclusions which may be drawn from the WEP performance are many. The provision of a multiplicity of independent telescopes with overlapping spectral coverage has contributed to the long and continuing useful life of the WEP.

The space vacuum has produced no recognizable deterioration in WEP performance. While the WEP design avoided the use of known outgassing type materials, to the date of writing there have been no catastrophic failures of the unsealed mechanisms,

no positive degradation of the coated optics traceable to the space vacuum, and continued operation of the current layer by layer potted HVPS. The space vacuum would seem to have contributed to the usefulness of mechanisms far beyond their anticipated operational life. Thermal variations are known to affect photometry sensitivity and may contribute to aging but both effects are detectable from the calibration slide data and therefore are removable from both short and long term relative observational data. Thermal excursions probably contributed to some of the anomalies noted.

The space radiation of the South Atlantic Anomaly continues to limit the orbital time during which good data may be collected. The space radiation may also contribute to the aging process noted in calibration slide sensitivity degradation. The space radiation is the likely cause for the S4F4 lithium fluoride interference filter degradation. However, these short and long term effects are predictable and removable from the observed data.

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